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The new generation of rocket engines, operating by ecologically safe propellant " liquid oxygen and liquefied natural gas(methane)"

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Annotation

The development of "Riksha" family launch vehicles operating with ecologically safe propellant LOX/Liquid Natural Gas (Methane) is now underway in Russia. These vehicles are capable of delivering 0,6 - 4,0 ton payloads onto low polar orbits. The vehicles use RD-182, RD-184, RD-185, RD-190 LRE developed by NPO " Energomash". The "Riksha" type rockets are intended for replenishment of orbital telecommunication satellite groups, for example, the ROSTELESAT system, after 2002.

The paper notes some agvantages of methane as a rocket fuel in comparision with kerosine.

The paper presents the results of research the engine cycle schemes, showing the energetic advantages of scheme with oxidizer - rich gas in compasion with other schemes considering the same engine dimentions.

It also presents the characterisics of RD -169, RD-184,RD-!85,RD-190 rocket engines, and also RD-182, RD-192 engines operating with methane instead of kerosene and representing the modifications of known RD-120K and RD-191 LRE.

It is showed that at the same development periods the methane engine modifications have specific impulse 20 sec hiqher than kerosene ones while remaining 70-80% of prototype hardware.

The paper proposes a conception of use of varions engine modules (EM) for advanced different class launch vehicles.

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Preface

XX century will be the century of information. This means for humanity the necessity of delivery in space on varions orbits, the constellations consisting of tens and handreds Earth satellites and the necessity of reqular substitution damaged satellites in the presence of the life - -period limitations.

It will require the utilisation of rockets varions classes with payloads from hundreds kilogramms to tens tons, low prime cost and ecologically safe

For these purposes the most suitable fuels in a pair with liquid oxygen are the already assimilated kerosine and hydrogen, and in perspective - metane.

At the first time the methane as a rocket fuel was mentioned ≈60year ago in the book V.P. Glushko and G.E. Langemak, however the methane utilisation (as well hydrogen) was restrained by their low density and by the priority of military developments operating by storable propellant.

The investigations of rocket engines operating by propellant "oxyqen - metane" are conducted in Academician V.P. Glushko NPO " Energomash" from 1981 in the application to commercial projects of heavy lift launch vehicles as well light and mtdium lift, at this areconsidered the various engines: thrust from 1kg to 200t(1kg,1t,5t,10t,40t,100t ,200t);

engine cycle:

closed oxidizer - rich gas generator (ORG) and fuel - rich gas generator(FRG);

staged combustin both the fuel and oxidizer(two gas qenerators);

tripropellant engire operating by oxygen, methane and hydrogen:

open scheme (gas generator cycle burning).

For every variants there are conducted the fuel cycles of calculations, the designings of aggregates and engines, there are estimated the energetic and mass- dimension characteristics.

Particularities of methane as a rocket fuel

The utilisation of metane (or liquefied natural gas(LNG), where methane - up to 98%) in comparison with to kerosene provides:

a) the hiqher energetic characteristics of rockets (more than 20...30% higher payload mass at the egual initial vehicle mass);

b)the better chamber cooling , the same heat flux may be take off by twice smaller methane flowrate; it means an additiional inerease of the specific impulse;

c)it is experimentally established the absence of carbon black formation in fuel - rich gas generator; this fact opens the possibility for utilisation of any engine cycles (ORG, FRG, two gas generators, tricomponent gas generator);

d) the higher ecological clealiness of combustion products and propellant components in the case of accidental drains (there are in absence

e) it's not reguired the special treatment of cavities between the control test and flight, that makes more easy the repeated utilisation;

f) more low cost (three times smaller than kerosene);

g) practically unlimited raw material base (Russia has 40% world resources, the first place in the world; gas will be enough during 100...120 years, oil - during 30..40 years).

h) The proximity of temperature ranges for liguid phases of oxygen and methane allows to employ the new constructive decisions on the vehicle, zhat promote the final vehicle mass decrease;i)the methane (LNG) might and must be utilzed in other industry branches as oil alternative(fuel - energetic complex, aviatiow, automobile, railway, sea trasport, agriculture, mode of life).

Compasion of engine cycles

In Rusia (USSR) almost all liqiid rocket engines (LRE) were created rising the scheme wirh ORG(tens) and with FRG - Only three (all with hydrogeh as fuel).

We consider as example three engine cycles for LRE with thrust ~ 200t at the utilization the same chamber geometry: engine cycle with closed oxidizer - rich gas generator (fig.1) engine cycle with closed full-rchgas generetor(fig.2,3); open engine cycle (fig.4.). The inverstigation of principal engine schemes with staged combustion was conducted in two directions:

the determination of maximal chamber pressure for every scheme: The determination of energetic charactirististics for every scheme at the really achievable and realizable chamber pressures and turbine pressure ratios.

The investigations for determination of maximal chamber pressures were conducted at the following data:

The temperature of generator gas, maximally allowable at the nominal regime: oxidizer rich gas 900K; fuel rich gas 1000K; he propellant component pressure at entrance of the chamber cooling tract for both schemes < 500kg/cm^2;

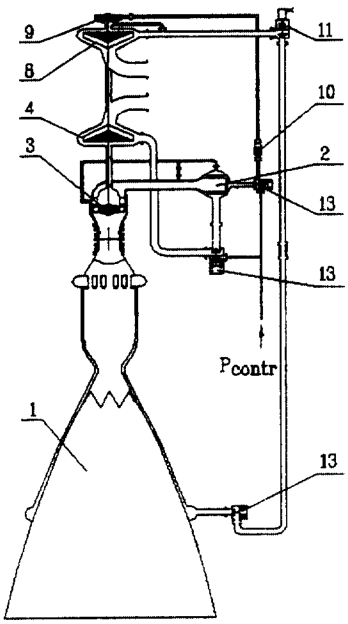


Fig.1 The principal sheme of engine with closed oxidizer – rich gas generator

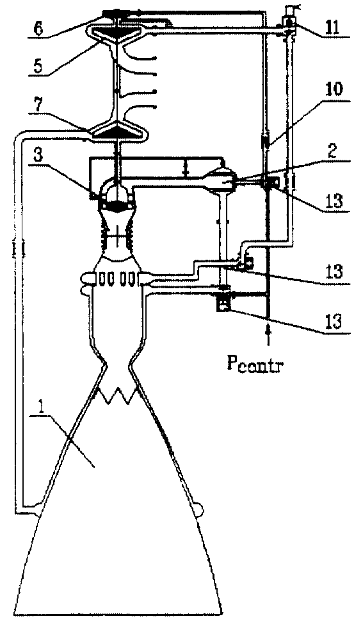


Fig.2 The principal sheme of engine with closed fuel – rich gas generator. Variant 1.

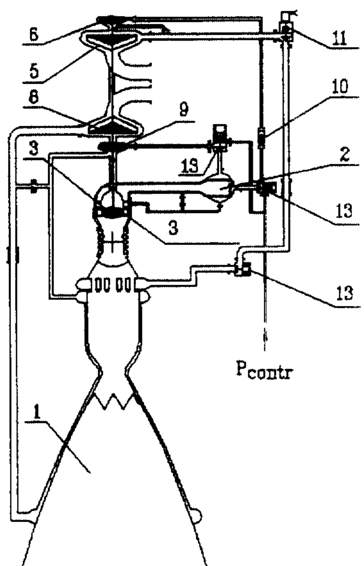


Fig.3 The principal scheme of engine with closed full – rich gas generator. Variant 2.

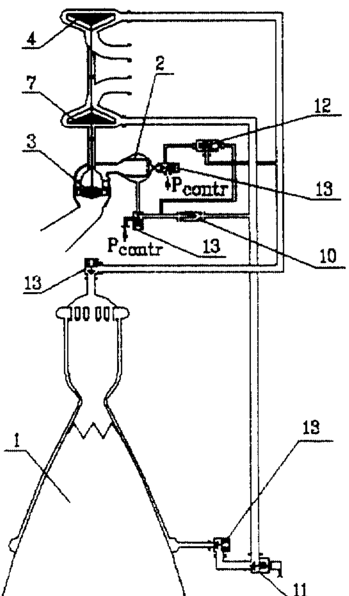


Fig.4 The principal scheme of engine with open cycle.

Designations: 1–chamber; 2–gas generator; 3–turbine; 4–oxidizer pump; 5–oxidizer pump 1; 6–oxidizer pump 2; 7–fuel pump; 8–fuel pump 1; 9–fuel pump 2; 10–regulator; 11–throttle; 12–gas generator

the same for both schemes the pressure differences on units of automatic control and regulation; the pumps and turbines, really achievable for prototypes;
the turbine pressure ratio not more than 2;
the same for both schemes fuel temperature rise in the chamber cooling tract.

The results of the investigations are presented in table 1 The received results of the studies, concerning the choice of optimal energetic scheme of engine, confirm so that the earlier received results and show that the scheme with closed oxidizer - rich gas generator at today achieved level of material properties and loads possesses the best energetic characteristics in comparison with the scheme with closed fuel - rich gas generator (taking account of the mass, the second scheme loses first scheme 2...3% the specific impulse)

Today NPO " Energomash" on the basis of the own expirience of the development of liguid rocket engines RD-170, RD-120, RD-180, etc. believes that scheme with closed oxidizer rich gas generator is the most assimilated and perspective.

Table 1

№	Parameter	ORG	FRG	Open CYCle
1	Engine thrust,t	207,8	200	215,2
2	Chamber vacuum specific impulse,sec	357,4	348,2	352,7
3	Engine vacuum specific impulse, sec	357,4	348,2	340
4	Tetperature of generator gas, k	890	1000	1100
5	Pressure at entrance of chamber cooling tract, kg/cm^2	420	503	400
6	Chamber pressure,, kg/cм^2	270	165	250
7	Turbine pressure ratio kg/cм^2	1,92	1,84	50
8	Engine specific mass,kg/t	16,3	16,0	14

<u>Engines for "Riksha" light class launch vehicles</u>

The "Riksha" launch vehicle is intended for launching 0,6 through 5 ton payloads onto LEO to replenish constellation of telecommunication satellites. Head developer - State Rocket Center (SRC) named after Makeev, Miass, Chelyabinsk region, Russia.

There are projects of 4 derivatives of "Riksha" launch vehicle. Table 2 shows their main performance characteristics.

Each of derivatives can be launched either from easy-to-build ground based launch pad or modified middle class sea ships.

"Riksha-0" launch vehicle uses module type RD-169 engine. 6 such modules having sea level nozzle constitute the first stage engines designated as RD-190.

1 module having upper stage nozzle (RD-185) is used on the second stage.

First and second stage modules differ from each other only by the nozzle expansion ratio and type of attachment to the vehicle thrust frame to provide gimbaling each nozzle for thrust vector control.

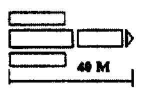
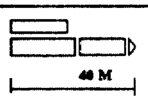
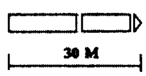
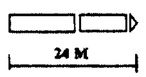
The use of module type engines allows to reduce development cost that was widely used during development of the engine by NPO Energomash.

Table 3 shows main performance characteristics of RD-169, RD-190, and RD-185 engines intended for the first and second stages of "Riksha-0" launch vehicle. The table also shows main performance characteristics of RD-183 engine used as a payload booster propulsion unit.

The feasibility of achieving presented characteristics, reliability, terms, and low cost development of these engines is based on NPO Energomash experience and the choice of engine internal parameters at well experienced level, see table 4.

Table 2

Main Performance Characteristics of "Riksha" launch vehicle family

	Lift-off Weight, t	Payload, t	First Stage Engines	Second Stage Engines	Rocket Scheme
Riksha	180	$4^{1)}$-$5,4^{2)}$	3xRD-182	1xRD-185	
Riksha-1	135	$2,2^{1)}$-$3,2^{2)}$	2xRD-182	1xRD-185	
Riksha-2	65	$0,6^{1)}$-$1,2^{2)}$	1xRD-182	1xRD-185	
Riksha-0	64	$1,1^{1)}$-$1,7^{2)}$	6xRD-169	1xRD-185	

<u>Note</u> 1) - 200 km orbit, ~90° inclination
2) - 200 km orbit, ~0° inclination
3) - diameter of each rocket section is 2.4 м.

Table 3

Performance Characteristics of LOX/Methane LRE being developed by NPO Energomash for "Riksha-1" launch vehicle

1	Characteristic	First Stage		Second Stage	Apogee Propulsion
		RD-169	RD-190 (6 RD-169)	RD-185	RD-183 Main Engine
1	Thrust, tf -Sea Level -Vacuum	 15 17	 90 102	 18,3	 1
2	Specific Impulse -Sea Level -Vacuum	 309 351	 309 351	 378	 360
3	Chamber Pressure, kgf/cm^2	150	150	150	75
4	Nozzle Exit Pressure, kgf/cm^2	0,51	0,51	0,036	0,055
5	$\sum z$	1	1	1	10
6	Mixture Ratio	3,4	3,4	3,4	3,4
7	Overall Dimensions, l -Height -Diameter	 1,7 0,5	 1,7 2,4	 3,3 1,5	 1,15 0.310
8	Wet Weight, kg	215	1470	415	60
9	Thrust Vector Control	2 Plane Gimbaling ±8°	2 Plane Gimbaling of Each Chamber ±8°	Two Plane Gimbaling ±4°	Two Plane Gimbaling ±10°
10	Development Period from Start of Financing	4 years	4 years	4 years	4 years
11	Status as to 1996	Project	Project	Project	Project

Table 4

Parameter Name	RD-170	RD-191	RD-169
Chamber Pressure, kgf/cm^2	250	250	150
Preburner Pressure, kgf/cm^2	546	519	327
Turbine Inlet Pressure, kgf/cm^2	519	519	325
Turbine Exhaust Pressure, kgf/cm^2	268	269	168
Turbine Pressure Drop	1,93	1,93	1,93
Preburner Temperature, K	807	787	578
Turbine Inlet Gas Temperature, K	772	787	578
Turbine Exhaust Gas Temperature, K	681	700	487
Pressure Downstream of Oxidizer Pump, kgf/cм^2	614	586,7	359
Pressure Downstream of Fuel Pump First Stage, kgf/cm^2	516	518	
Pressure Downstream of Fuel Pump Second Stage, kgf/cm^2	821	853,2	408

NPO Energomash conducted fire testing of module type chamber (150 kgf of thrust) with LOX+Methan (38 tests with total accumulated time up to 1000 sec) which verified analytical calculations and discovered no new problems in operating cycle.

NPO Energomash executed a contract with Russian Space Agency (RSA) that stipulates performing fire testing of actual chamber and preburner early 1998.

Experimental engine is manufactured by Krasmash (Krasnoyarsk), but fire testing is supposed to be performed at NIICHIMMAS (Sergiev Posad, Moscow region)

Modernization of existing engines by replacement of kerosene with methane

To reduce cost for development of new engines NPO Energomash conducted some research activity aimed to modify previously developed engines by replacement of LOX/Kerosene propellants with LOX/Methane. The goal was also to use as much existing prototype hardware as possible, especially chambers.

To NPO Energomash evaluations the replacement of kerosene with methane would require replacement of 20 to 30 % of engine components, in particular:

- replacement of fuel main and boost pump
- replacement of fuel duct materials with cryogenic resistant ones that are used in other engines,
- replacement of rubber seals with metallic ones,
- refinement of main chamber and preburner injector elements flow areas, controls, thrust and mixture ration control valves.

The refinements mentioned above do not bring on any technical difficulties, design approaches required for that are used in our activity.

It is necessary to note that manufacturing tooling remains entirely.

The following prototype engine hardware would be used: main chambers, preburners, turbine, LOX main and boost pumps, controls, LOX ducts, thrust frames, gimbal units and much other.

Results of conducted investigations are presented in table 5.

Table 5 also shows comparative information on RD-191, RD-120K, RD-134, RD-161 prototype engines and their derivatives RD-192, RD-182, RD-167, RD-160.

Table 5

Performance Characteristics of LOX/Kerosene and LOX/Methane LRE being developed by NPO Energomash

№	Characteristic	First Stage				Second Stage			
		RD-191	RD-192	RD-120K	RD-182	RD-134 4 MC + 1 TPU	RD-167 4 MC + 1 TPU	RD-161	RD-160
1	Fuel	Kerosene	Methane	Kerosene	Methane	Kerosene	Methane	Kerosene	Methane
2	Thrust, tf -Sea Level -Vacuum	 196 212	 201 218	 72-78* 81-89*	 74-81* 83-92*	 35	 36	 2,0	 2,0
3	Specific Impulse, s -Sea Level -Vacuum	 311 337	 330 356	 295-298* 334-336*	 311-316* 351-353*	 357	 379	 360	 380,6
4	Main Chamber Pressure, Pк, kgf/cm2	262	262	166-175*	166-175	170	170	120	
5	Nozzle Exit Pressure, kgf/cm2	0,75	0,75	0,24	0,24	0,05	0,05	0,05	0,05120
6	Mixture Ratio	2,6	3,5	2,6	3,4	2,6	3,4	2,6	3,69
7	Overall Dimensions -height, m diameter, m	 4,05 2,0	 4,05 2,0	 2,8 1,5	 2,8 1,5	 1,6 2,4	 1,6 2,4	 1,7 0,764	 1,7 0,764
8	Wet Weight, kg	3230	3300	1433	1500	540	570	124	129
9	Thrust Vector Control	Two Plane Gimbaling ±8°		Two Plane Gimbaling ±6°		Two Plane Gimbaling ±3°		Two Plane Gimbaling ±6°	
10	Development Period from Start of Financing	4 years	4 years	3 years	3 years	4 years	4 years	4 years	4 years
11	Status as to 1996	Project, MC Available	Project, RD-191 Prototype	RD-120 Prototype Da=1,8m	RD-120K Prototype	Project	Project	Project	RD-161 Prototype

*-the range is due to the possibility to change the throat diameter and main chamber pressure.

Development concept of methane engines for advanced different class launch vehicles

The concept of methane liquid rocket engines (LRE) for near-term advanced launch vehicles is as follows:

- Stage propulsion system is built up of engine modules (EM)
- EM is single chamber engine having pump fed propellant supply system and used in different combinations as first stage, upper stage, or strap-on booster propulsion.
- EM (or its chamber) is capable of gimbaling in two planes.
- There are three classes of EM: light (15...20 tf of thrust), medium (70...90 tf) and heavy (190...220 tf).
- Light, medium, and heavy class engine modules are used in light, medium, and heavy class launch vehicles correspondingly.
- EM of each class is produced in two modifications - sea level and vacuum.
- Sea level EM is used for first stage propulsion and strap-on boosters.
- Vacuum EM is used for upper stage propulsion.
- Engines that are built up of sea level EMs are configured as gimbaling units having minimum necessary degrees of freedom and consisting of 2, 3, and from 5 to 7 EMs equally situated relative to the engine center line and each other.
- First stage engine and strap-on boosters are unit consisting of 5, 6 (preferred), or 7 EMs having three rotational degrees of freedom.
- Upper stage engine consists of 1 vacuum EM having two rotational degrees of freedom.

- The RD-169 (RD-185) engine especially developed for "Riksha" methane launch vehicle is supposed to be used as light class EM.
- The RD-182 engine capable of gimbaling in two planes is recommended for use as medium class EM.

- The RD-192 methane engines could be used as heavy class EM.

Conclusion

There is an option for consideration - the possibility to use RD-169, RD-182, RD-190, RD-192 engines on advanced launch vehicles. There are results of analysis showing the feasibility of creating launch vehicles without hydrogen and kerosene such as "Angara" that, with the use of methane engines, would have the same payload capacity and lift-off weight as for the case of use of hydrogen and kerosene.